

VERITAS Telescope 1 Relocation: Details and Improvements

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The first VERITAS telescope was installed in 2002-2003 at the Fred Lawrence Whipple Observatory and was originally operated as a prototype instrument. Subsequently the decision was made to locate the full array at the same site, resulting in an asymmetric array layout. As anticipated, this resulted in less than optimal sensitivity due to the loss in effective area and the increase in background due to local muon initiated triggers. In the summer of 2009, the VERITAS collaboration relocated Telescope 1 to improve the overall array layout. This has provided a 30% improvement in sensitivity corresponding to a 60% change in the time needed to detect a source.

1. Introduction

The imaging atmospheric Cherenkov technique (IACT) was developed at the Fred Lawrence Whipple Observatory (FLWO) resulting in the first very high energy (VHE; $E > 100$ GeV) detection of the Crab nebula in 1989 [1]. In the twenty years since that first publication there have been VHE detections of over 100 objects including pulsars, blazars, pulsar wind nebula, supernova remnants and starburst galaxies. Since VHE photons do not penetrate the atmosphere, IACT telescopes measure the Cherenkov light generated by particle showers initiated by the primary photons interacting with our atmosphere. This Cherenkov light appears as a two dimensional ellipse when imaged by an IACT telescope camera. The shape and orientation of the ellipse in the camera indicate whether the shower was initiated by a gamma ray or by a cosmic ray which can also cause a particle shower.

The current generation of IACT instruments involve arrays of telescopes. The addition of multiple telescopes allows for a more accurate determination of the shower parameters. One of the most powerful aspects of this technique is that the light pool of the shower defines the collection area ($\sim 10,000$ m²) which is more than adequate to compensate for the low flux of VHE gamma rays. Currently there are four major experiments in operation, HESS, an array of four IACT telescopes located in Namibia, MAGIC, an array of two telescopes located in the Canary Islands, VERITAS in southern Arizona and CANGAROO in Australia. MAGIC just completed a major upgrade by adding a single telescope and stereo trigger and HESS is in the process of building an additional very large telescope. This contribution details part of the ongoing upgrade program being undertaken by the VERITAS collaboration.

VERITAS [2, 3] is an array of four 12 m diame-

ter IACT telescopes located in southern Arizona at the FLWO at an altitude of 1268 m. VERITAS detects photons from astrophysical sources at energies between 100 GeV and 30 TeV. The VERITAS telescopes consist of four identical alt-az mounted Davies-Cotton reflectors with an f number of 1.0. The mirror area is approximately 106 m². Mounted in the focal plane is a camera made up of 499 pixels consisting of 28 mm Photonis phototubes. VERITAS has a three level trigger, the first at the pixel level, the second is a pattern trigger which triggers when any three adjacent pixels trigger. Finally, an array trigger fires if any 2 or more telescopes trigger within a set time frame. For more details on the VERITAS hardware, see [3].

For historical reasons, Telescopes 1 and 4 were erected in close (~ 35 m) proximity. Even though VERITAS met all of its original design specifications, this resulted in a significant collection area overlap and increased background due to cosmic rays and local muons. In fact, all of the published VERITAS analysis included a cut that rejected events that only triggered Telescopes 1 and 4. Simulations performed in the summer of 2008 suggested up to a 15% improvement in sensitivity if Telescope 1 was moved ~ 200 m eastward from its initial position. Assuming that Telescopes 1 and 4 are redundant and can be considered a single telescope, a 1/3 improvement is expected by adding an additional telescope.

Based on these data, it was decided to relocate Telescope 1 to a more ideal location providing a more symmetrical layout to the VERITAS array (see Figures 1 and 2). It was decided to relocate Telescope 1 instead of Telescope 4 to allow for the refurbishment of the oldest telescope in the array which was originally installed at the FLWO as a prototype in 2002. The relocation of Telescope 1 is part of an ongoing upgrade program [4] which recently included an improvement in the optical point spread function (PSF) [5]. The improvement in the optical PSF was accomplished using

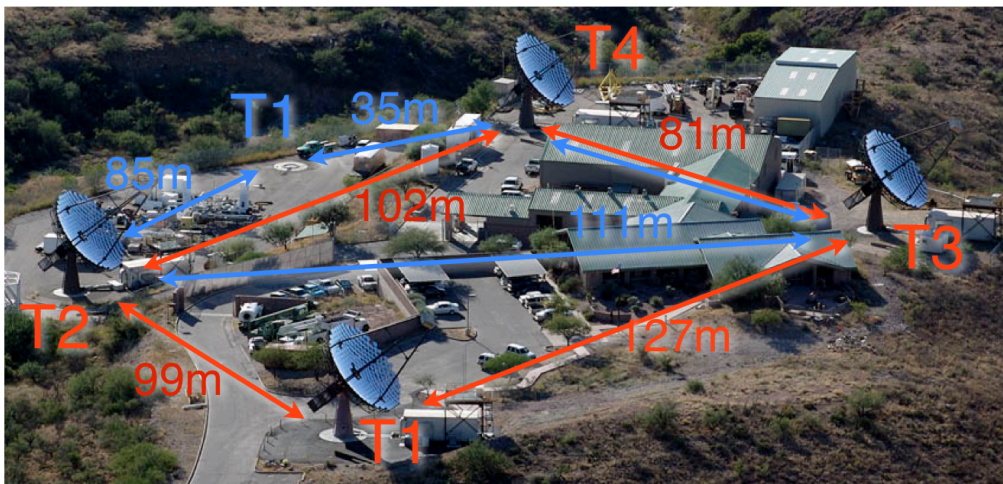


Figure 1: aerial view of the new VERITAS array layout with Telescope 1 relocated to the front of the FLWO administrative complex. The original array layout position is marked in blue while the new one is in red. Note the short distance (35m) between the original Telescope 1 position and the position of Telescope 4.

a novel mirror alignment system which resulted in a 25 - 30% improvement in the PSF. This optical PSF improvement also contributes to the enhancement in sensitivity discussed here and cannot be disentangled from the overall results. The move of Telescope 1 combined with the improvement in the optical PSF has resulted in making VERITAS the most sensitive VHE telescope array in the world capable of detected a 1% crab nebula signal in less than 30 hours.

Since VERITAS does not operate during the summer months (approximately July through August), the move of Telescope 1 was scheduled to take place during this time to minimize the impact on the observing program. Telescope 1 was shutdown 6 weeks early (May 4, 2009) so that it would be operational by the first of October. The move was completed on September 4, 2009 and is estimated to have taken 2600 person hours of labor. Ten days later on the 14th scheduled operations began with the full array, over two weeks earlier than expected. By September 17th normal operations had resumed. In total, VERITAS only lost 6 weeks of full four telescope operations and these were with the old array layout. The final array layout, while not entirely symmetric, is a much better layout for a VHE instrument. Figure 1 shows an aerial view of the VERITAS array with the old layout shown in blue and the new layout in red. While the old layout had inter-telescope distances ranging from 35 m to 127 m, the new layout distances range from 81 m to 127 m. Figure 2 shows a schematic representation of the array viewed from directly above. Also shown as a black arrow is the relocation of Telescope 1.

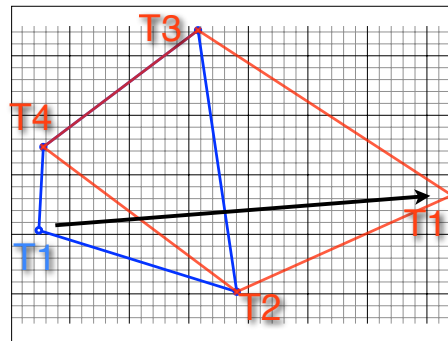


Figure 2: Schematic of the array as viewed from directly overhead. The blue lines are for the original array layout while the red are for the new array layout. The black arrow indicates the relocation of Telescope 1. The small grid squares are 5 m on a side.

2. Results

VERITAS data are calibrated and cleaned initially as described in [6]. After calibration several noise-reducing cuts are made. The VERITAS standard analysis consists of parametrization using a moment analysis [7] and following this, the calculation of scaled parameters are used for event selection [8, 9]. This selection consists of different sets of gamma-ray cuts, determined *a priori*. Depending on the strength and expected spectral index of a source, different cuts are chosen. For example, a source with the strength of the Crab would use a looser set of cuts than a weak source at the 1% Crab flux level. These two sets of cuts are called loose and hard cuts. Additionally, soft and standard versions of these cuts are used for soft (approximately spectral indices of 3 and above) or

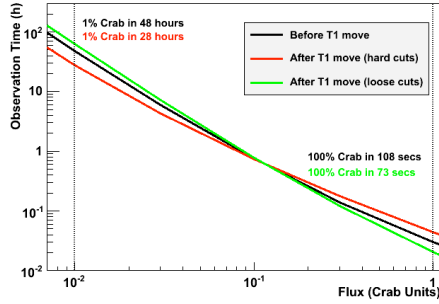


Figure 3: The time needed to detected a source at the 5σ level vs. that source's flux in units of the Crab Nebula's flux. This is shown for the original array layout and for the new array layout with two different sets of event selection cuts. Note that it would take 48 hours to detect a 1% Crab source with the original array layout and only 28 hours with the new array layout.

standard (Crab-like 2.5 spectral index sources). The choice of which cuts to use are determined prior to the analysis. Figure 3 shows the observation time needed to detect an object at the 5 standard deviation (σ) level. Before the relocation of Telescope 1, a 1% Crab flux source could be detected in 48 hours while after the move it only takes 28 hours loose cuts. Similarly, it takes 72 seconds to detect the Crab nebula after the move with hard cuts, as opposed to 108 seconds before the move.

Another way of looking at the sensitivity of VHE instruments is to calculate the integral flux sensitivity above a energy threshold. Shown in Figure 4 are the integral flux sensitivity vs. Energy Threshold for several different instruments. In red is the original VERITAS layout while the new VERITAS layout is shown in black (based on Crab observations; the dashed sections are under evaluation). The integral flux sensitivity of VERITAS above 300 GeV is $\sim 30\%$ better after the move. This corresponds directly to a 60% reduction in the time needed to detect a source (for example, a 50 hour observation before the move is equivalent to a 30 hour post move observation). For comparison are shown the initial HESS sensitivity [10] shown as the blue dashed line (note that this is the original HESS sensitivity curve before any mirror reflectivity degradations). The integral sensitivity of a single MAGIC-I¹ telescope is shown as the green dashed line. Another thing to note is that the sensitivity of VERITAS has slightly degraded at the lower end due to the loss of sensitivity to the lowest energy showers.

Figure 5 shows the energy resolution of the VERITAS array as well as the angular resolution. These

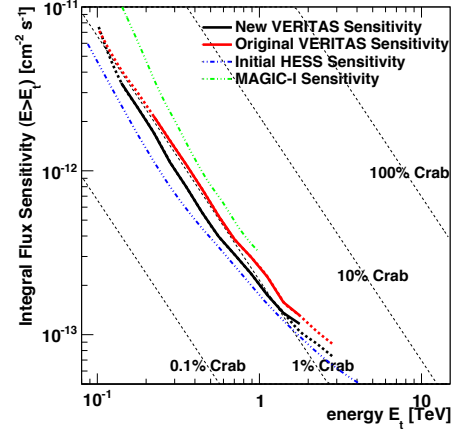


Figure 4: Integral flux sensitivity vs. Energy Threshold for several different instruments. In red is the original VERITAS layout while the new VERITAS layout is shown in black (based on Crab observations; the dashed sections are under evaluation). Initial HESS sensitivity [10] is shown as the blue dashed line and MAGIC-I¹ is shown as the green dashed line. Note that the integral flux sensitivity improvement of VERITAS above 300 GeV is $\sim 30\%$.

two features are similar to the numbers calculated for the original VERITAS array layout. Both plots are for observations at 70 degrees elevation. The angular resolution and energy resolution change for observations undertaken at different elevations.

3. Summary

The VERITAS collaboration relocated Telescope 1 and dramatically improved the optical PSF during the summer of 2009 as part of an ongoing upgrade program. These studies indicate that the upgrades have improved the sensitivity of VERITAS by 30% resulting in a 60% change in the time needed to detect a source. The higher sensitivity achieved with VERITAS allows the detection of more objects in a shorter amount of time, effectively doubling the observation time. The ability to detect marginal sources such as M82 and to do deep observations of known objects has drastically improved.

In addition to the telescope relocation and optical PSF improvements, there are several other upgrade plans being discussed which are described in [4] and are planned to be implemented in the next few years. These upgrade plans include the installation of higher efficiency photon detectors which would result in a 17% improvement in the sensitivity of the array and/or the installation of a topological trigger which would consist of transmitting image parameters from the camera directly to the array trigger allowing for

¹<http://www.astro.uni-wuerzburg.de/mphysics/>

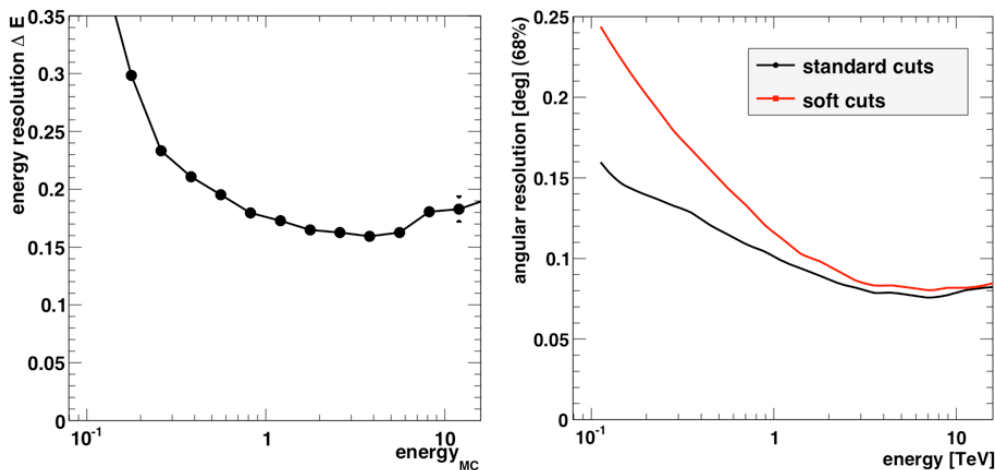


Figure 5: Left: the energy resolution of VERITAS vs. simulated energy at 70 degrees. Right: the angular resolution (68% containment) of VERITAS vs. real energy at an elevation of 70 degrees for two different sets of event selection cuts (black is for a crab like source and red is for a softer spectrum source).

real-time event classification for gamma/hadron separation. In addition to these baseline upgrades, the expansion of the array by adding more telescopes or an active mirror alignment system is also possible. This ongoing upgrade program, beginning with the optical PSF improvement and the relocation of Telescope 1 will continue to make VERITAS competitive in the coming decade.

Acknowledgments

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